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## ROYAL ASTRONOMICAL SOCIETY OF CANADA

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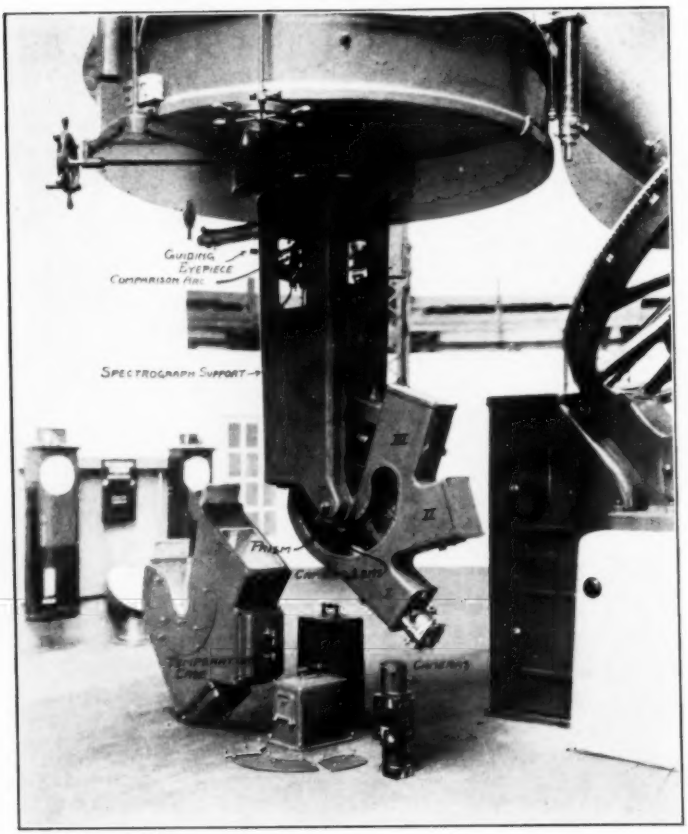
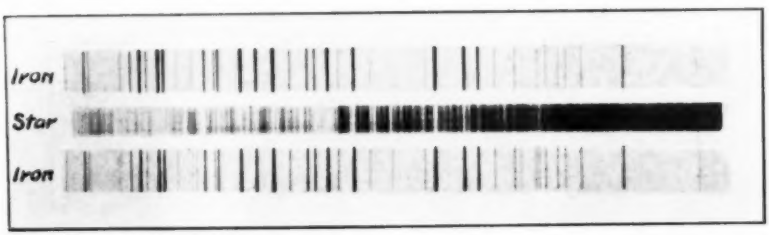
PLATE XVII




*Above.*— Stellar Spectrograph attached to the 72-inch Telescope. Temperature case removed.
*Below.*— A Portion of the Spectrum of Arcturus.

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# THE SPECTROSCOPE AND ITS WORK

by

WILLIAM H. CHRISTIE

## PART 1

### THE SPECTROSCOPE AND THE SPECTRUM

The present article has been prepared in order to assist some of the members of the Royal Astronomical Society of Canada to understand more fully some of the more technical papers that appear from time to time in this JOURNAL. In a society like ours there are a large number of members to whom the technical terms are more or less unintelligible, and it is with the hope of interesting these in the work of the most important instrument of research that the physicist and astronomer has at his disposal that these articles are written.

The most important part of the prism spectroscope is, of course, the prism, so this vital unit will be described first. The prism is a wedge-shaped block of glass with its faces inclined to each other at an angle of about sixty degrees; though there are various other forms of prisms, such as constant deviation and direct vision prisms, differing greatly from this form, but these need not be described here.

The modern prism is one of the finest examples of the master optician's art, and so accurately are its faces shaped—or figured, as it is termed—that they nowhere deviate from truly plain surfaces by more than about a millionth of an inch. The blocks of glass from which the best prisms are made must be perfectly free from strains and must be homogeneous throughout. As large blocks

of optical glass of the desired purity are difficult to obtain, they tax the skill of the expert glass maker to the utmost to produce them.

I think everyone is familiar with the beautiful colours with which objects appear to be fringed when viewed through a wedge-shaped piece of glass, such as the bevelled edge of an ornamental light in a door, or by reflection in the bevelled edge of a mirror. The colours are caused by the light passing through the wedge-

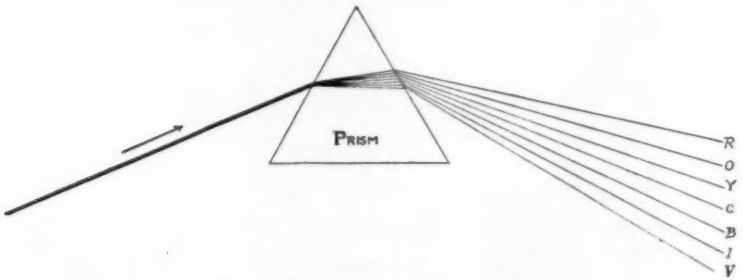



Fig. 1. Dispersion of light by a Prism.

shaped edge of the glass, for if a ray of light falls on the face of a prism it is refracted, or bent, on passing into the glass, and on emerging it is bent still more. The amount by which the beam is bent depends upon the colour of the light, red light being bent the least and violet the greatest. A glance at Figure 1 will make this clear to the reader. Here we have a beam of white light falling upon a prism and as it enters its direction is changed. But as white light contains "all the colours of the rainbow" some of the light is bent more than other portions; and the rays upon emerging are deviated still more, as shown. If this dispersed beam is allowed to fall on a white screen, a band of colour will be seen, red at the top and violet at the bottom, with the intermediate colours—orange, yellow, green, blue and indigo—coming between.

Such a band of colour is called the spectrum, and further, by reason of its continuity, a continuous spectrum. As obtained above the spectrum is not pure, however, due to the overlapping of the colours to a certain extent. In order to make it as pure as possible it is necessary to make the aperture, or slit, from which the

light reaches the prism, very narrow in the direction parallel to the edges of the prism, and furthermore, the light coming from this slit must be converted into a parallel beam before it falls upon the prism. The piece of apparatus that performs this function is called the collimator and consists of a narrow pair of metal jaws at one end of a tube, at the other end of which is a lens at a distance from the slit equal to its focal length. This is shown in Figure 2.

After passing through the prism and being dispersed, the light now falls on a second lens, which brings each of the monochromatic beams, into which the incident beams have been split up, to a focus where the spectrum may be seen with an eyepiece; on a screen; or recorded on a photographic plate as indicated in Figure 2. In the photographic form the complete instrument is called the spectograph, and in the visual form, the spectroscope. A small laboratory spectroscope, by Hilger, is shown in Figure 3.

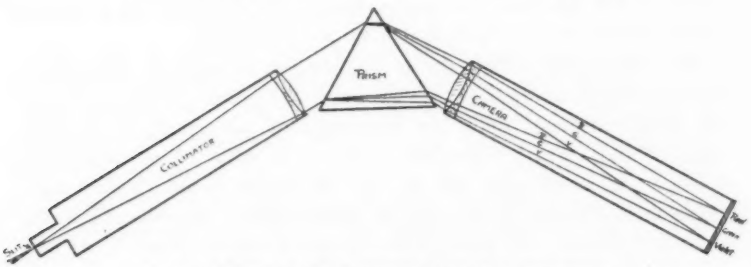



Fig. 2. Diagram of the Passage of Light in a Spectroscope.

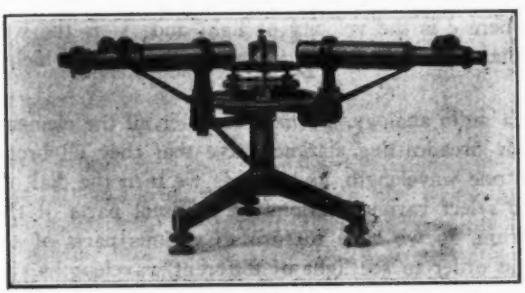


Fig. 3. A Typical Laboratory Spectroscope.

When any substance is heated to an incandescent vapour it gives out light which is characteristic of that substance. Sodium, for example, of which common salt is a form, burns with a yellow light, and if we illuminate the slit of a spectroscope by the light from a hot flame into which a little common salt has been introduced, we shall find that its spectrum consists in the main of two bright yellow lines, very close together, superimposed upon a faint continuous background. These lines invariably appear in the same position in the spectrum. If one of the lithium or strontium salts is introduced into the flame, we shall find strong lines in the red end. On introducing a mixture of two or more salts the characteristic lines of each will be seen in their respective positions.

The lines of which we have been speaking are nothing more nor less than monochromatic images of the slit itself, for, as the slit was not brightly illuminated with light of all colours, the only parts of the spectrum to appear bright are those which have the same colours as the light that illuminates the slit.

The sensations which the eye interprets as colours are caused by the impact of radiant energy upon the retina of the eye, and the colour depends upon the frequency of this energy. In these days of radio nearly everyone understands what is meant by frequency and wavelength, but in case the reader is not familiar with these terms it may be as well to define them. Wavelength is the distance between two consecutive points of similar phase in a train of waves, as from crest to crest or trough to trough, and frequency is simply the number of waves passing a given point in a second, or $c/\lambda$, where $c$ is the velocity of light and $\lambda$ is the wavelength of the radiant energy — light, in the cases with which we are dealing.

To use a radio analogy, we may consider all the elements giving out light as broadcasting stations, save that they all broadcast on more than one wavelength, and just as we turn the dial of a radio receiver to select various stations on different parts of the broadcast spectrum, so we have to turn to various parts of the visual spectrum in order to see light of different wavelengths.

If we illuminate the slit of a spectroscope with sunlight we shall

see a bright continuous spectrum, with the same series of colours, crossed by numerous dark lines. Most of these lines can be shown to correspond to the bright lines of hydrogen, helium, iron, titanium and many other elements by comparing the spectra of the sun and various elements, either directly or indirectly. If, for example, the light from a sodium flame illuminates one half of the slit while the other half is illuminated with sunlight, the two spectra will be seen side by side and the two bright lines in the sodium spectrum will be seen to correspond to two dark lines in that of the sun.

On placing the sodium flame in front of the slit, so that the sunlight has to pass through it, it might be thought that the two dark lines would appear brighter. Such is not the case, however; they become darker, and the greater the thickness of flame, within certain limits, through which the sunlight has to pass, the darker they become. These lines, although called dark, are only so by comparison with the bright background.

The part of the sun from which we receive most of the light is composed of the incandescent vapours of many elements, and above this region, which we call the photosphere, is a region of cooler and less dense gases—the reversing layer. The light emitted by the hot gases of the photosphere is partially absorbed by the cooler gases of the reversing layer, each element in this surrounding shell absorbing energy of the same frequencies that it itself emits, but, as the gases of the reversing layer are not so hot as those of the lower layers, they do not emit the light as strongly as the latter, hence this light is weakened and appears in the spectrum as dark lines. It is the study of these dark absorption lines that tells us so much about the sun and stars, and how some of our information is gleaned from them will be discussed in the following parts of this series.

As an illustration of a modern spectroscope adapted for astronomical—or rather, astrophysical—research, the writer has chosen the universal spectrograph attached to the great 72-in. reflecting telescope at Victoria, B.C. This is illustrated in the accompanying Plate XVII, on which the various parts are marked. This particular instrument may be used with one, two or three prisms; as

shown it is arranged for use with one prism. The end of the camera can be seen protruding from the lower box-like projection; the two others, marked II and III, serve to take the camera when two or three prisms are being used. The collimator is invisible in the photograph, being contained in the part of the instrument hidden by the spectograph support. The prism may be seen in front of the camera lens.

For stellar work a spectograph must be made extremely rigid; if the parts bend, the definition of the photographs is spoilt, besides introducing spurious shifts in the positions of the spectral lines. For this reason the casting that forms the support for the prisms and other optical parts must be designed so as to be practically inflexible. Changing temperature would cause the amount by which the incident beam is bent to vary, as well as altering the focus of the camera and collimator, hence it is necessary to keep the temperature as nearly constant as possible. This is accomplished by enclosing the instrument in a case padded on the inside with felt over which heating wires are strung. When the temperature falls below a predetermined value, an electric current is automatically switched on which heats the wires in the case, thus warming the air; then, when it has reached the correct temperature, the current is cut off. In this manner the temperature can be kept constant to within a few hundredths of a degree.

In photographing the spectrum of a star, the light falling on the great mirror of the telescope is condensed to a minute disc of light on the slit of the spectroscope and kept there throughout the exposure by means of a guiding eyepiece that allows the observer to see the image of the star on the slit. Before the photographic plate is removed a comparison spectrum is photographed on either side of that of the star. This is done by illuminating the slit on either side of the star image with the light from an iron or other suitable arc. On development the comparison spectrum is seen on either side of that of the star so that a standard scale of reference is provided by which the positions of the lines in the star spectrum can be determined.

The length of the spectrum obtained with one prism and the

medium-focus camera of the spectrograph described above is about one and one-third inches, and the width from one to two one-hundredths of an inch, depending upon the effective length of the slit used. Even to make them this wide, the star image has to be trailed up and down the length of the slit between the boundaries which limit its length. No colours are, of course, visible in the photographs of the spectrum, it simply appears as a narrow dark strip (being a negative) crossed by a number of lighter lines. The region of the spectrum that appears in the photograph depends upon the colour-sensitivity of the emulsion of the plate used. The ordinary photographic plate is not sensitive to red light, therefore that part of the spectrum does not appear; only a band between the green and ultra-violet being recorded. A portion of a spectrogram of the bright star Arcturus, in the constellation of Boötis, is reproduced in the accompanying plate. The comparison lines are due to the light from an iron arc.

## Part II

### How the Radial Velocities of the Stars are Determined

The determination of the velocities of approach or recession of the stars forms an important branch of astrophysical research. In the study of the motions of the stars it is necessary for us to know three quantities before their true velocities and motions can be determined. The required data are: the radial velocities, the proper motions and the parallaxes. The radial velocity can be determined only with the spectroscope, and is the velocity of the star in the line of sight. The parallaxes and proper motions are determined by methods that will not be discussed here, but they will be briefly defined. The parallax of a star is a measure of its distance, and is the angle that the line joining the sun and earth would subtend as seen from the star. The proper motion is the minute arc over which a star appears to move in a given interval of time. From these two it is evident, after a little consideration, that we can calculate the velocity of a star across the line of sight; hence, knowing the transverse and radial components of a star's velocity, it is a simple matter to determine the true direction and magnitude of a star's

motion by an application of the well-known theorem of Pythagoras.*

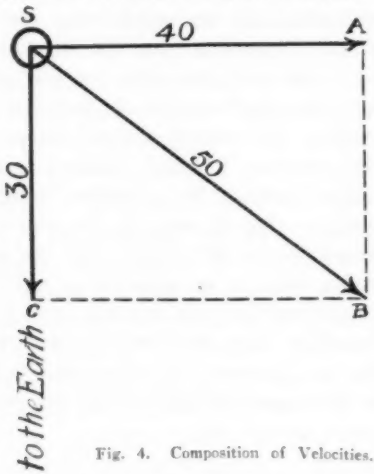



Fig. 4. Composition of Velocities.

As an example, suppose that the line *SC*, (Fig. 4), represents the radial velocity of a star and *SA* its velocity across the line of sight. On applying the above theorem the true velocity comes out to be $\sqrt{30^2+40^2}=50$ units and the direction of its motion will be along the line *SB*.

To illustrate the effect of a star approaching or receding from

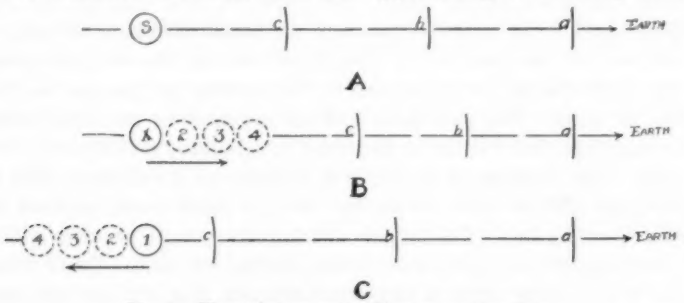



Fig. 5. Illustrating an approaching or receding Star.

**The sum of the squares of the sides of a right-angled triangle is equal to the square of the hypotenuse.*

the observer, as observed with the spectroscope, let us consider a star *S*, at rest as shown in A, (Fig. 5); and let *Sa*, *Sb* and *Sc* represent the distance light has travelled in 3, 2 and 1 seconds, respectively. The wave-fronts, represented by *a*, *b* and *c*, will be exactly the same distance apart, *i.e.*, the distance light travels in one second, or about 186,000 miles in round numbers, and the intervals between them will contain the same number of waves of light of any given wavelength.

Now suppose that the star is approaching the observer as shown in B, so that it has the positions 1, 2, 3 and 4 at the beginning of the first, second, third and fourth seconds. The light emitted by the star when in position 1 will reach *a* in three seconds. At the beginning of the second second the star will be in position 2, and the wave-front emitted when in this position will reach *b* in two seconds, somewhat closer to *a* than in the first example because the star has moved over the interval 1 to 2 between the times wave-fronts *a* and *b* were emitted.

As the intervals *a* to *b*, *b* to *c* contain exactly the same number of waves as in the case of the star being at rest, they must be more crowded together than in the former case or, in other words, their wavelength has become less. In a similar manner the light waves coming from a star receding from the observer will be less crowded than in the first example, hence the wavelength of the light is slightly lengthened.

The reader will remember that the position of a line in the spectrum depends upon its wavelength, so that if a body emitting light approaches or recedes from the observer the spectral lines will be shifted; towards the violet if approaching, and towards the red if receding.

The measurement of this shift of the lines in the spectrum tells us the velocity of the star's approach or recession. The ratio of the original wavelength of a line to the velocity of light being equal to the ratio of the change in wavelength, due to the star's motion, to the velocity of the star, or, if *V* is the velocity of the star, *c* the

velocity of light, $\lambda$ the original wavelength of a spectral line and $\lambda'$ its new wavelength, we have

$$\frac{\lambda}{c}=\frac{\lambda-\lambda'}{V}$$

$$\text{or} \quad V=\frac{\lambda-\lambda'}{\lambda}c=\frac{\Delta\lambda}{\lambda}c$$

where $\Delta\lambda$ is the change in wavelength. The velocity will come out positive if the star is receding and negative if approaching.

The shift of the spectral lines is determined by means of a measuring engine; one of these instruments, by Gærtner, is illustrated in

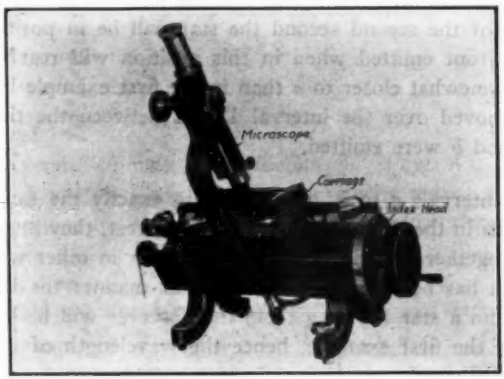



Fig. 6. A Gærtner Measuring Machine.

Fig. 6. The carriage on which the photographic plate rests is moved by means of a very accurate screw, to one end of which is attached a drum or "index head". This index head is accurately divided into a number of divisions. Each turn of the drum moves the carriage through a distance equal to the pitch of the screw and, by the aid of the graduations of the drum, the distance through which the carriage has been advanced can be determined very accurately,—to less than 1/25,000th of an inch with the instrument illustrated.

A microscope is rigidly attached to the frame of the instrument, and this is focussed on the spectrum. A cross-wire in the focal

plane of the eyepiece serves to determine the centre of the field and this is set on the comparison and star lines as the plate is moved. Two or more settings are made on each line, and the readings on the scale noted, the mean of these measures is then taken and set down. After measurement in one direction the plate is reversed and again measured, and the mean of the two sets of measures taken in order to eliminate any personal tendency to set more to one side of a line than the other. These measures are now reduced.

The comparison spectrum serves as a scale by which the wavelengths of the star lines can be determined and then, by using the formula derived above, the velocity can be determined. A much simpler and more rapid method, however, is in use in observatories where a large amount of radial velocity work is done. A table is computed, from measures of a plate, which gives the settings that should correspond to the comparison lines, and also the star lines if the star possesses no velocity relative to the observer, on any plate taken under exactly similar conditions to the standard. As the conditions are very rarely the same, due to differences in temperature, etc., slight corrections must be made to the observed settings on the comparison lines in order to make them agree with the computed values. Similar corrections are then made to the star lines, and this corrected value is subtracted from the computed. The remainder, when multiplied by a constant computed for each line, termed the $rV_s$, gives the displacement of the line in terms of the star's velocity in kilometers per second. The mean value for all the measured star lines is then taken.

The resulting velocity is that with which the observer and star were approaching at the time of observation, but this contains several velocities not due to the star. These are: the motion of the sun (and with it the earth) through space; the earth's motion around the sun; the axial rotation of the earth; the movement around the centre of gravity of the earth-moon system.

The first of these is an unknown quantity so all the observations are referred to the sun as a standard of reference. The last quantity is so small as to be negligible except in the most refined work; the other two, however, must be removed from the observed velocity

before we have the velocity with which the star and the sun are approaching or receding.

## Part III

### Spectroscopic Binaries and how their Orbits are Determined

Many of the stars we see as single points of light—even with the most powerful instruments—are in reality double; yet so vast a gulf lies between us and these far distant suns that they appear as one. Such double stars as these reveal their true nature only when investigated with the spectroscope and are termed spectroscopic binaries to differentiate them from the visual pairs.

As the reader is probably aware, no two heavenly bodies could remain relatively at rest if they were in close proximity, the enormous forces of their mutual attraction would draw them together. In order to remain apart they must possess orbital motion; each revolving about their common centre of gravity, just as the earth-moon system does. The path these bodies follow, unless there is a third body affecting them, is an ellipse and, as the reader may not be familiar with this figure, a few lines devoted to it will not be out of place.

If we stick two pins firmly into a flat board and over them place a loop of thread, longer than necessary to go around them, we can draw an ellipse by inserting the point of a pencil in the loop and, keeping the thread taut, running it around the pins. By varying the distance apart of the two pins, which mark the foci of the ellipse, ellipses of varying character may be obtained. If the pins are close together the figure will be nearly circular, in fact a circle may be looked upon as a special form of ellipse, one with the two foci coincident; if the foci are relatively far apart the resulting figure will be a very flat oval.

The form of an ellipse—whether it is nearly circular or very much elongated—is designated by the term eccentricity; the eccentricity being the ratio of the distance between the foci to the greatest diameter of the ellipse (the major axis). If, for example, the major axis is ten units long and the distance between the foci is seven units, the eccentricity will be 7/10 or 0.7.

A heavenly body moving in an elliptical path follows a simple

law which was first enunciated by Johann Kepler ,and is known as Kepler's second law. This law states that the radius vector sweeps over equal areas in equal times.

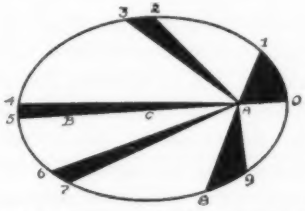



Fig. 7. Illustrating Kepler's Second Law

In Fig. 7 an ellipse has been drawn in which *A* and *B* are the foci and *C* the centre. The lines *A*0, *A*1, *A*2, etc., are radius vectors and the shaded areas are equal; hence, according to the law enunciated above, a heavenly body moving in such an orbit would move over the arcs 0-1, 2-3, 4-5 etc., in equal intervals of time. It will be seen from this that the body must travel with varying speed if its orbit is other than circular.

For the sake of simplicity let us consider a body moving in a

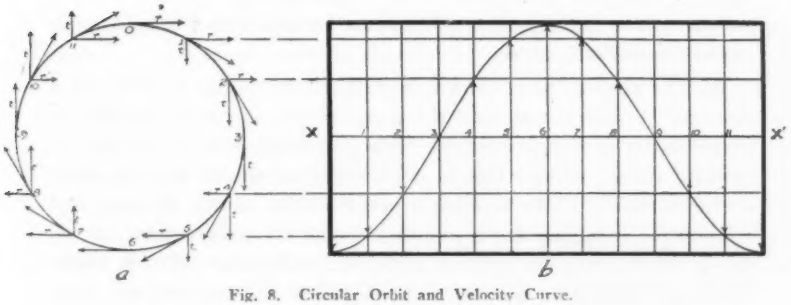



Fig. 8. Circular Orbit and Velocity Curve.

circular orbit as shown in *a*, Fig. 8. The arrows tangential to the orbit represent the velocity of the star in its path—their length being proportional to its velocity. This velocity can be resolved into two components, one in the line of sight, and one at right-angles to this line (see part I). The component in the line of sight

is marked *r* and that at right-angles to it, *t*. (The observer is supposed to be situated far to the right of the diagram.) When the body, which we shall assume is moving in this path, is in the position marked 0 it is approaching the observer with its full velocity. When it arrives at position 1 it will no longer be approaching with its full velocity for there is now a component of its motions at right angles to the line of sight, and in position 2 it will be approaching still less rapidly. When at the point of its orbit marked 3 it no longer approaches, but, for an instant, has no velocity in the line of sight. The radial velocity appears again, however, as soon as this point is passed, this time away from the observer. This gradually grows in magnitude until at position 6 a maximum velocity of recession is reached, after which the velocity in the line of sight again declines until at 9 it is once more zero. From this point the velocity of approach increases until the body is back at 0, completing the cycle.

Now if we draw a line XX′ (b, Fig. 8), and draw equally spaced lines at right angles to this at 0, 1, 2, 3, etc., and then measure off distances from XX′ proportional to the arrows representing the radial velocity, starting at 0 and measuring above the line if the body is receding, and below if it is approaching, we can draw a smooth curve through the points thus located and obtain what is called the velocity curve.

As has already been shown in part II the radial velocity of a star can be determined with the spectroscope. From a number of observations of a spectroscopic binary, it is possible to obtain the velocity curve, though this is not always as simple as it appears on the surface. If the star has a period of, let us say, 20 days, and we observe it nightly for a month and plot the observations, as we did in determining the velocity curve of our circular orbit, it would be an easy matter to determine the period of the star and the form of the velocity curve. But such an occurrence is very rare, for a number of observations may be scattered over months, or even years, and from these the velocity curves have to be obtained.

As an easy example look at Fig. 9. In the upper diagram eighteen imaginary observations are plotted in the order in which they are

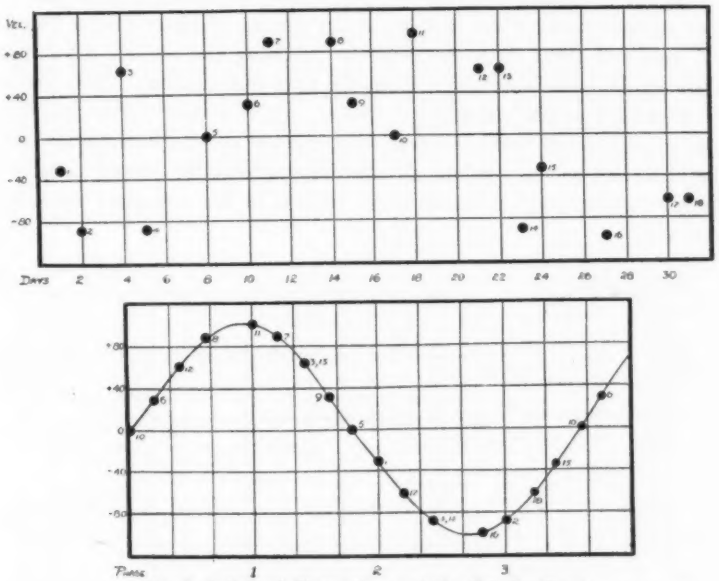



Fig. 9. Individual Observations and the Velocity Curve.

supposed to have been obtained. What is the period of such a body? The velocity curve is shown below and the period turns out to be 3.6 days. The observations are numbered so that they can be identified.

The method of obtaining these velocity curves from scattered observations will now be described. After the period is suspected an arbitrary zero of time, called the epoch, is selected and multiples of the suspected period are added to this and the total subtracted from the times of observation; the differences always being less than the period. This gives the phases of the observations, which, if the period is correct, will fall on a smooth curve. If the later observations do not quite fit the curve the period is adjusted until they do so. These phases are the fraction of the period which has elapsed since the foregoing time of zero phase, which is, of course, an exact multiple of the period.

In the foregoing diagram one day before the zero might be selected as our epoch, which will make the phases of observations 1 and 2, two and three days, respectively. Adding the period, 3.6 days, we get 2.6 to be subtracted from the next observations. This gives 1.4 and 2.4 as the phases of 3 and 4. Again adding 3.6 we get 6.2 to be subtracted from observation 5, the phase of which comes out as 1.8, and so on. When all the observations are plotted according to phase they take the form shown in the complete velocity curve.

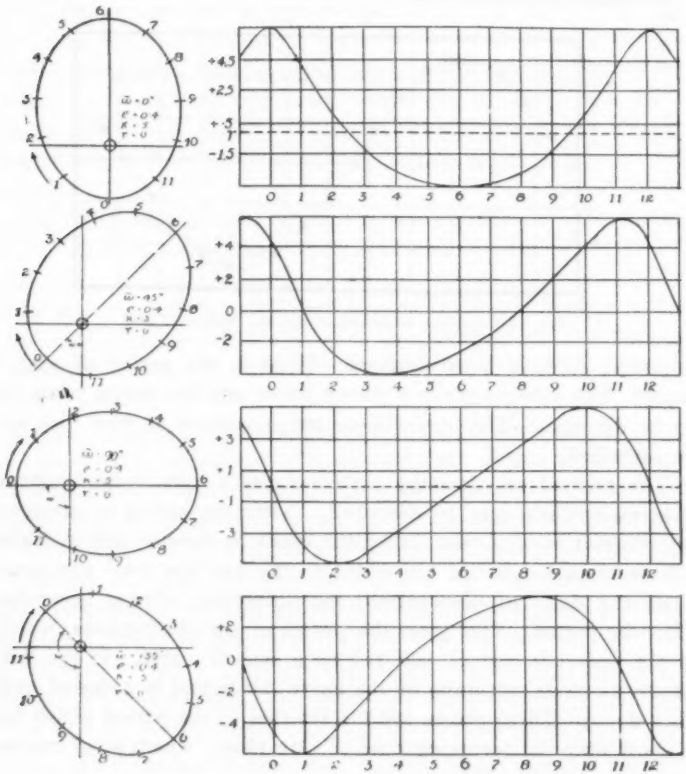


Fig. 10. Velocity Curves for Elliptical Orbits.

The velocity curves seldom assume such simple forms as we have been considering, for these were circular orbits. When the orbit is an ellipse it may take any one of an infinite number of curves, eight examples of which are shown in Figs. 10 and 11. The form of these curves depends upon two factors—the eccentricity of the ellipse and the longitude of periastron.

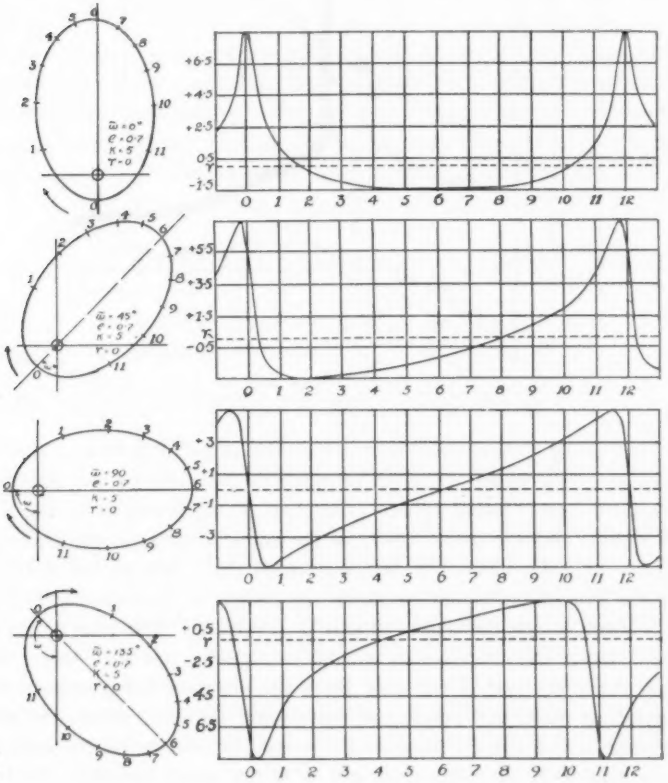



Fig. 11. Velocity Curves for Elliptical Orbits.

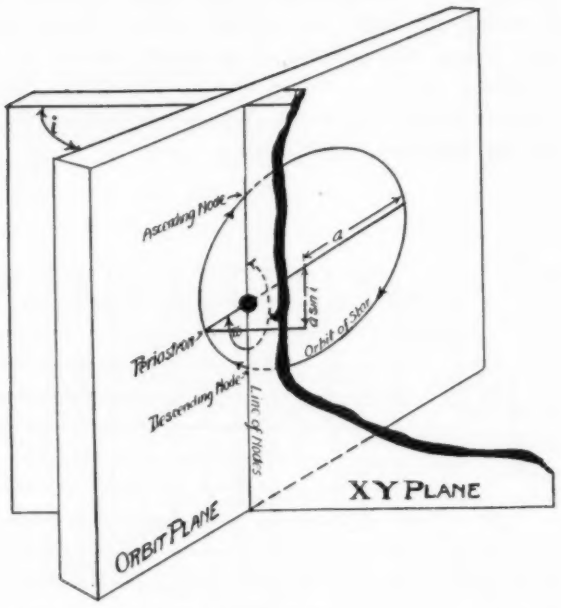



Fig. 12. The Orbit of a Binary Star as seen from the Earth.

In Fig. 12 I have tried to portray the orbit of a binary star as seen from the earth. The "XY" plane is the plane of the sky, tangential to the celestial sphere (therefore at right angles to the line of sight), and the orbit plane, as the name implies, is the plane in which the orbit lies. The intersection of these two planes is termed the line of nodes and contains the centre of gravity of the system about which the observed star is revolving. The two points in the orbit at the intersection of the two planes are the nodes; the one where the star is receding from the observer being termed the ascending node, the other, the descending node. When the star moving in this orbit is nearest the centre of gravity of the system, it is said to be in periastron and it is the angle between the line of nodes and periastron, measured from the ascending node in the

direction of the star's motion, that is called the longitude of periastron, which quantity is usually designated by the Greek letter omega $\omega$.

In the accompanying velocity curves $\omega$ has been given as 0°, 45°, 90° and 135° and the eccentricities as 0.4 and 0.7. The variation in the form of the velocity curves with changing $\omega$ is clearly shown. If these curves are viewed in a mirror held upright at the top of the page they will represent those for 180°, 225°, 270°, and 315° respectively. The orbits are supposed to be viewed from the right.

From the foregoing paragraphs it will be seen that, once the velocity curve of a spectroscopic binary has been drawn, it is possible to obtain the elements of the orbit. Some of these have been defined above, but will be included in the following list in order to make it complete. The elements of a spectroscopic orbit are:

| | |
|---|---|
| $P$ | The period of one complete revolution of the star in its orbit. |
| $T$ | The initial epoch; selected as some date of periastron passage. |
| $e$ | The eccentricity of the orbit. |
| $\omega$ | The longitude of periastron. |
| $\gamma$ | The velocity of the system as a whole. |
| K | The semi-amplitude of the range in velocity. |
| $a \sin i$ | The projected semi-major axis. |
| $\frac{m_1^3 \sin^3 i}{(m+m_1)^2}$ | The mass-function; given in terms of the sun's mass as unity. |

The velocity of the system is, as the term implies, the velocity with which the system as a whole is approaching or receding from the observer and the $\gamma$ axis, indicated by a broken line in some of the curves, divides the velocity curve into two parts of equal areas, above and below. The semi-amplitude of the velocity range is simply one half the observed range in velocities. $a \sin i$ is the length, in kilometers, of the projection of the semi-major axis of the ellipse on a plane passing through the line of nodes and the observer: this plane is not shown in the diagram, but can be represented by a sheet of paper held perpendicular to the page, and with

its edge in contact with the line of nodes. $a$ is the semi-major axis of the ellipse and $i$ the angle of intersection of the two planes which, of course, cannot be determined by spectroscopic observations alone.

The above elements may be visualized more readily if the reader cares to take the trouble to make a stiff paper model consisting of two pieces at right-angles to each other, representing the $XY$ plane and the plane passing through the observer, while the orbit plane, intersecting these on the common line of intersection, (the line of nodes), may be inclined at varying angles to them.

As all observations differ from the true value by an amount depending upon their quality, the observations of a spectroscopic binary will not fit any computed curve exactly, due to the errors of observation. The difference between the observed quantities and the computed values should, however, be as small as possible. In order to make them so a solution is made for the most probable value of the elements by a method known as that of the "least squares". After the preliminary elements have been obtained from the provisional velocity curve a mathematical solution is run through in which each observation exerts itself, according to its quality, to make the sum of the squares of the residuals (the differences between the observed and computed values), usually written $\Sigma\ pvv$, as small as possible. This process gives the amounts which must be added to or subtracted from, the preliminary elements in order to make them fit the observations as well as possible.

# RADIO TALKS ON ASTRONOMY, OVER CFCT, VICTORIA, B.C.

By W. E. Harper

## XV. Double Stars

(January 9, 1929)

To the naked eye there are many stars which appear to be single and yet when viewed with a telescope of high resolving power are seen to be in reality double. This doubling may come about in either of two ways. First, the two stars may just chance to lie in the same direction from us so that they appear in our telescopes side by side. While thus appearing to be close to each other they may be separated by exceeding great distances, one perhaps being near to our solar system and the other an almost infinitely great distance from it. In such cases there is no physical connection between the two stars and such cases are known simply as *optical* doubles. Knowing the total number of stars down to any limit of faintness, the mathematician can calculate the chance that two stars will thus happen to lie side by side and he finds it exceedingly small. The number of such optical doubles in the sky is, therefore, very limited and the vast majority of double stars belong to what are known as *physical* doubles. In these the two components are physically connected, being relatively close to each other and mutually revolving the one about the other.

The discovery of such visual binary stars came about almost accidentally. They were found when looking for something else. The English astronomer, William Herschel, was seeking to determine the distances of the stars and conceived the idea that these close doubles might serve his purpose. Up to his time they had been considered as purely optical doubles, the components of which might be at very different distances from the earth. Herschel reasoned that if this were so their angular separation should undergo changes at different times of the year. As we swing about the sun at an average distance of 93 million miles we are first at one

side of it and six months later at the directly opposite side. Some closing in or opening out of the pair might be expected when viewed from positions 186 million miles apart. Such a principle is fundamentally sound and was later developed to give us the distances of the nearer stars. Herschel's measures were possibly not precise enough to show the expected apparent displacement but as he continued his observations from year to year he found that certain doubles were actually revolving the one about the other. It is said of Saul of old that he set out to seek his father's asses and found a kingdom instead. Herschel set out to seek one thing and found a greater; namely that the laws of gravitation as known upon the earth hold true for the distant stars as well. Just as the earth and other planets are swayed in orbits about the sun so, too, distant suns mutually attract and move in orbits about each other.

A notable list of workers in Europe and America have added to the known number of visual binary stars. Among English astronomers the Herschels, father and son, made large contributions; so did the Struves for Germany, whilst American names include among many others, Burnham, Hussey and Aitken, the latter being the present greatest living authority upon the subject. Burnham was for the most part an amateur, beginning in 1870 with a small six-inch telescope which he purchased and mounted in his garden in Chicago. He discovered 1340 new doubles, made many thousands of measures of other known pairs and published his monumental catalogue about 1906, containing 13,365 entries. It is still a standard work of reference although it will soon be superseded by one in preparation by Aitken of the Lick Observatory.

One can easily see that nearby physical systems of this character will be more readily discovered than others more distant because on the average the angular separation will diminish with the distance. Of the stars down to magnitude 6.5, which is considerably fainter than we can see with the naked eye, it has been found that about every ninth star is a visual binary. If more powerful telescopes were available it is only logical to suppose that many now appearing as single would show as double. This view is strengthened by confining our attention to those which are relatively close to us. On the average the brightest stars are the closest and

if we consider twelve of the brightest we find that seven are binary. Moreover, in the case of those whose distances have been reasonably well determined we find that out of twenty-four of the nearest no less than sixteen are binary. This confirms our information from other lines of evidence that every third, or possibly every second star, is a physical system consisting of two suns more or less equal in mass and brightness, and in mutual revolution the one about the other.

The periods of revolution of these components about each other vary from a few years up to several hundred and indeed to more than a thousand years. The star *Delta Equulei* with a period of *5.7* years was until recently the shortest known of these but one announced a few months ago from the southern hemisphere has a period of only *3.5* years. There are 30 or more with well determined orbits whose periods are less than 50 years, and probably reliable orbits are known for at least 100 of these visual binaries When we are dealing with those of long period much uncertainty exists by reason of the fact that they have been observed over only a small proportion of their whole orbit. Future generations will have to complete the orbital data but it would appear to be a safe guess that many such systems are under observation to-day, the complete path of which will not be observed for another thousand years.

Let us try to visualize one of these systems, taking for our example the double star that until recently was the one of shortest known period, namely *Delta Equulei.* While this star is just nicely visible to the naked eye, we have learned that it is so far removed from us that light, which reaches us from the sun in a little over eight minutes, requires about sixty years to come from the system to us. In other words we are seeing the double star by light which left there sixty years ago. The two components are quite similar in make up, each having a mass about three times that of our own sun with linear dimensions greater accordingly. As the temperature of the components is some 500° higher than that of our sun, their surfaces radiate more light and heat than corresponding areas on the sun. Thus each component has intrinsically about twice the brightness of our sun. The components are separated by a distance six times as great as separates the sun and ourselves

and their orbits about each other are noticeably elliptical. One should state though that while this is a well known double star, only the best telescopes will show it as such since the components are so close together, relatively speaking. Their maximum separation is always less than half a second of arc. This angle is equivalent to one inch seen from a distance of six and a half miles. Since all the measures are of angles smaller than this it goes without saying that good instruments, steady seeing conditions and a trained observer are essential to a successful determination of the orbit.

While the components of this system are markedly similar such does not hold true for all binary systems. Quite often the colours of the components are distinctly different, signifying that they are at different temperatures. Again it is found that the masses of the components are dissimilar but as a general rule the combined mass of the two components is not much more than twice the sun's mass. If at the formation of the binary system one of the components has less mass to start off with it will run through its evolutionary career at a faster rate than its more massive companion. On the upward path to the zenith of its light-giving powers the less massive will be hotter and bluer than its companion. After it has attained its maximum brightness and has started down the sunset slopes of its career towards extinction, it passes through the bluish-white, yellow and reddish stages ahead of its more massive brother and thus for the remainder of its existence is always redder than the latter.

A word in conclusion as to their origin. In the heavens are vast masses of nebulous matter which under the all-pervading power of gravitation are condensing. Unequal distribution of matter with other causes sets up rotation in the condensing mass. At a certain critical density, less than a quarter that of the density of water, the mass, due to its increased rotation, breaks in two. Thus are close doubles formed. More widely separated pairs may have originated from the existence of two separate nuclei in the original nebulous mass about which the matter condensed. Much more research is necessary before we can be certain of many points in this interesting theory.

## XVI. Variable Stars

(February 13, 1929)

My last talk was on "Double Stars" and I left with you the conception that the stars are not always single as they seem, but quite often consist of two components in mutual revolution about each other. To-night the idea I wish to present is that they are not all constant in light and as the years go by and better instruments for measuring their light are invented, it would begin to appear that the star whose light does not vary is almost the exception rather than the rule. Such a statement three centuries ago would have been scoffed at, if indeed it did not land the one who gave utterance to it in prison, seeing that the stars were looked upon as heavenly bodies, without blemish and unchangeable.

But in 1596 a bright star was discovered in the constellation of Cetus which, after a few months, disappeared from view only to reappear in its former identical position at a later date. It was seventy years later though before it was discovered that these striking changes in brightness were recurring regularly every eleven months. The star was named "Mira" meaning wonderful and justly so, for at maximum its brightness is sometimes 600 times that at minimum.

The second variable star to be discovered was in the constellation Perseus. It was named "Algol", or, in the language of the Arabs who discovered it, El Ghoul. They probably witnessed something strange and threatening in its blinking light. A century or more passed before the explanation of its variations was forthcoming and they were rightly interpreted by a deaf mute named Goodricke. He showed how an eclipse by another dark body, about which Algol was revolving, would account completely for the observed rapid diminution and recovery of light.

This deaf mute also discovered a variable star in the constellation Cepheus, namely Delta Cephei, whose variations are of a pattern followed by many others, so that the general name Cepheids applies to all of this kind. In this class there is a rapid increase of light to a maximum and afterward a slow and fitful falling away to a minimum. The range of brightness is rarely greater than six-fold.

At the dawn of the nineteenth century, nine variable stars of more or less regularity were known to astronomers, and an inkling was had of the various classes into which they can be sub-divided. That number increased to thirty-eight by the middle of the century. Towards its close many observers entered the field and during the early years of the present century a scheme to enlist the co-operation of a great army of amateurs has been evolved. The result is that to-day we know of the existence of at least 5,000 variables and for many of these, thanks to the amateurs, we know considerable of the character of the light variations that are taking place.

There are four main groupings:—

(1) There are the Novae, those stars which for a brief space have their day and cease to be, shining for a time so brightly that all men wonder at them, then slowly and intermittently wane to extinction. Of this class I spoke in one of these talks over a year ago.

(2) The long-period stars, those whose periods are usually about a year; stars that glow with a ruddy light, and whose punctuality is not always to be relied upon. Such a variable is Mira Ceti, referred to a moment ago, and when we consider that changes occur which vary their light five hundred or a thousand fold can we wonder at slight irregularities in the period?

(3) The short-period stars whose cycle of variation is completed in a few days and which is of the Cepheid character previously described. Seemingly as a subdivision of this group we have stars which complete their whole variation in a few hours. Such a class is frequently found in great globular clusters of stars and have yielded valuable information about the cluster.

(4) The Algol variables which are close binary stars revolving in a plane which passes through our earth so that their light changes are due to partial or total eclipse. I shall elaborate upon the type star of this class. Its period has been very accurately determined since it has been observed for over 250 years. Every 2 days, 20 hours and 49 minutes the components make one complete circuit about each other. For 59 hours of its period the star remains approximately constant in brightness, during the next 5 hours it loses two-thirds of its light and during the following 5

regains its original brightness. Any persons sufficiently interested can by communication get a star-chart to locate it and follow the changes for themselves.

At first it was thought that all the light was given off by the main star and that the other component was wholly dark. Ten or a dozen years ago, when more sensitive instruments were designed to measure a star's light, Stebbins showed that when the bright body was passing in front of the supposedly dark one a diminution of light occurred, proving that the second body was also luminous to a certain extent.

The eclipse theory has been tested by measuring the velocity of the main light-giving star. It is found to be approaching, to be crossing in front of the darker one and to be receding at just the times required by the eclipse theory and no reasonable doubt remains as to this being the true explanation. From a combination of the light and velocity curves, we can deduce much information about the relative sizes and masses of the two components. The brighter star has twice the mass of the other but is only two-thirds its size.

About 200 such eclipsing variables are known and information as to their sizes, masses and corresponding densities has been determined for a great number of them. While the hotter stars have densities of a uniform nature and ranging from 1/20th to 1/10th that of our sun, we find in the cooler stars densities of two distinct orders. In one the density is comparable to that of our sun; in the other, densities as low as 1/500,000 are found. Thus these eclipsing variables have led to the knowledge that there are in the skies stars of enormous dimensions with exceedingly low densities.

On a former occasion I told you of the Novae type of variable, or new stars, which flare up unexpectedly. I need say nothing more here than that they are rare phenomena—probably not more than a score of bright novae being witnessed per century. We have been particularly favoured in our day as six have been noted since the beginning of the twentieth century. It remains to speak, then, of the long-period variables and the Cepheids.

The most numerous class is that of the long-period variable where the period is of the order of a year and large variations of light occur. Probably 4,000 of the total number are of this

class but the underlying cause yet remains unknown. It is known, though, that all these variables are red stars and the redder the star the longer the period of variation and the greater range of such variation. These stars are all giants of a very high order. At maximum brightness Mira Ceti (omicron Ceti), the typical star of this class, is known to have a diameter 300 times that of our own sun, with probably a hundred-fold greater luminosity. In its analyzed light, particularly at minimum, we recognize the presence of the bands due to titanium oxide, which substance can only form at relatively low temperatures. The light variation is large relative to the variation in total radiation and such is what we would expect at low temperatures where there is a rapid change in luminous efficiency with a small change in temperature. Possibly a mean temperature of 2000°C, with a 20 per cent variation on either side of the mean, would account for the observed fluctuations in light and heat. It may be that the outer regions of the star become periodically clouded over, owing to an accumulation of opaque material of some sort, and the heat accumulated below this veil increases until it bursts its barriers and streams out rapidly.

Time does not permit me to deal with the remaining class of variable, the most important of all, the Cepheids. Perhaps in my next address I may tell how these Cepheids, with their peculiar type of variation, have been used to indicate the distances at which they are found. It is a fascinating story if only I can present it aright.

## XVII. DISTANCE INDICATORS

(March 13, 1929)

In my last address I spoke on two kinds of variable stars. In the first class the variation in light was found to be due to the eclipse of one star by another as the two components of the physical system mutually revolved about each other. In the other case the cause of the variation was not so well understood, but for some reason these long-period variables changed their output of light several hundred fold from maximum to minimum brightness.

To-night I want to tell you about another class of variable star which has come to be used as a measuring rod for deriving the distances of the stars. In these variables the range of brightness is

only two or three-fold but they go through their variations with clockwork regularity whether their period of variation be one day or one month. Moreover, their variation in light is of such a character that it cannot be mistaken for some other kind. These stars increase in light power very rapidly from minimum until they attain their maximum brightness. Afterwards they decline in brightness much more slowly than they rose, until once more they reach their minimum.

Let us try to picture one of these glowing suns, for as most of you know, all the stars we see are simply bodies like our own sun, though on the average possibly more massive and correspondingly more luminous. Their great distances from us is sufficient to cause them to appear as mere points of light. The diameter of our sun is about 864,000 miles, which in round numbers we may speak of as slightly less than a million miles. The diameter of the typical star of this class of variable is of the order of 23 million miles. While they are thus of much greater volume it does not follow, however, that they are of corresponding greater mass, since it is found that their densities are but a small fraction of that of our own sun.

The surface temperature of the sun is in the neighborhood of 6000°C.; for these particular stars the surface temperatures average about the same, ranging from about 5000° to 8000°. But on the score of luminosity our typical variable would completely outshine the sun. If the two were placed equally distant from us this typical star in Cepheus would be 625 times as bright as our own sun. Thus the characteristic of these particular variables is that they are enormous spheres of glowing gases at low densities and radiating several hundred times the energy of our sun—in short they are giant stars.

The cause of their variation in luminosity has for a long time been an object of investigation. While there is not complete unanimity on the subject, it is pretty well accepted that the star is pulsating, alternately contracting and expanding and thereby causing variations in the radiative mechanism of the star. Gravity acts in the star just as on the earth, tending to draw all masses on its surface as near to the centre as possible. Opposed to this is the internal pressure trying to force the matter outward. Under normal conditions a balance or equilibrium would be effected. But if,

for some cause, probably external, the star should be compressed until its radius became, let us say, ten per cent smaller, let us see what would happen. The compression would heat the interior gases, increasing the pressure outwards and if the external force had passed away the star would start to expand and would return to its original size. When it reached it, however, it would still be expanding rapidly, and the inertia of the moving matter would carry it beyond its original size before it would come to a standstill. Then, the pressure being reduced as well as the temperature lowered, the force of gravity would again dominate and contraction would once more set in. In this way one can see how pulsations can be set going in the stars. By reason of the elasticity of the gases, of which the star is composed, the pulsation when once started will continue for long ages with only slight changes.

The velocity at which these outer portions of the star are moving, first towards us and afterwards away from us, can be determined by the spectroscope, and from the time required for a complete pulsation to take place we can calculate the total change in the dimensions of the star. The change in the diameter is only about 8 per cent., which is not an impossible figure. Calculation shows also that such a change would result in a change in temperature of about 500° each way from the mean and this change is ample to account for the variation in luminosity which is observed.

But the most important point has to do with a connection which exists between the actual luminosity of the star and the period of the pulsations. One can well believe from our everyday experiences with matter of different kinds that the denser the material constituting the star the more quickly will the changes of compression and expansion follow each other. Thus the more extended and luminous the star the longer will it require to make a complete pulsation. To each size of star then, loosely speaking, corresponds a definite period of oscillation. This relation between the absolute brightness of the variable star and its period of pulsation is suggested by theory, but it is a fact discovered independently by observation. It is thus known that a star 100 times as luminous as our sun would pulsate in half a day, one 250 times as luminous as the sun would require 2 days, our typical star with 625 times the luminosity of the sun would require 5.3 days, as observed, and

very luminous ones, say 10,000 times that of our sun, would require over a month for one complete pulsation.

Now we can reverse the procedure and say that if we find such a variable with a period of 5.3 days it will be practically identical in real luminosity with our typical star in Cepheus and therefore one of 625 sun-power. For others whose periods may be found we can assign the particular sun-power to fit their cases, for these variables wherever found all follow the same law. Now it is a very simple matter to observe the light changes going on in one of these stars and thus determine the period. From the relation just established between period and real brightness we arrive at the actual luminosity.

To get the corresponding distance of the star is then a very simple matter. Let me illustrate. If you stand on the street and look at a row of similar street lamps you realize that they get dimmer and dimmer as the distance increases. If one is twice as far away as the other it will appear only one-fourth as bright, if it is five times as far away it will show only one twenty-fifth as bright; the luminosity decreases as the square of the distance. Since you can measure accurately how bright the star *appears* to be and since your relation shows how bright it *actually* is, a moment's calculation is sufficient to determine just how far away it must be to shine with the brightness it does shine with. This is the principle of using these variables as measures or indicators of stellar distances.

To sum up.—Certain stars, called Cepheid variables, vary in the light sent to us both as to its quantity and quality and the variation is of such a character as to be easily recognized wherever found. These variations are due to throbbings or pulsations of these giant stars. By determining the period required for such a star to wax and wane we can deduce its real brightness since a relation connecting the two quantities has been established. Then, knowing its real and apparent brightness, a short calculation suffices to deduce its distance.

## XVIII. THE STARRY UNIVERSE

(April 10, 1929)

Those of you who were listening in on the second Wednesday of last month may recall that I was speaking of a certain kind of

variable star which we called a Cepheid, from the model star in the constellation Cepheus. There was a relation shown to exist between the period of variation and the absolute brightness which enabled us to deduce the distance of any star of this particular type. I had intended speaking to-night upon some great distances that have been so determined and the knowledge they have given us of the extent of the universe. I find, however, the subject is too long for my ten minutes and I shall break it in two, confining myself to-night to giving you a conception of what is known as our galactic universe.

To some, the term universe may mean the earth; to others, the solar system with all the planets and their attendant satellites; to others again who have had the privilege of a broader education, the term universe has to do with practically all the stars that can be seen with the aid of telescopes. There is an even wider conception than this, but we shall reserve it for a later chat, confining ourselves to-night to the millions of stars which constitute our own particular universe.

The naked eye can see approximately 5,000 stars; with the largest telescope so far constructed—the 100-inch one at Mount Wilson, California—2,000 millions can be seen and long exposure photographs make us aware of many, many more in our universe—though not without limit. These are all bodies like unto our own sun, some smaller, some larger, some cooler and some much hotter. They are not all equally distant from us, nor distributed uniformly around us in space. The general form they occupy in space may be likened to a thin watch or, better still, to two dinner plates placed face to face. That is to say, they extend much farther in one direction than in a direction at right angles thereto. We can prove this for ourselves by noting how the suffused glow from the thousands of faint, distant stars causes that encircling band of light in the heavens, so appropriately called the Milky Way.

Thus these millions of stars are congregated in a lens-shaped space of enormous dimensions. These are so great that the ordinary unit of distance, the mile, is of no service as the numbers that would be used to express our results would be so large as to be

unwieldy. We adopt a new unit of length, the light year, which is simply the distance light will traverse in one year. Its velocity has been determined very carefully and is found to be 186,285 miles per second. Thus it will flash around our earth between seven and eight times per second, and will come to us from the sun, a distance of 93,000,000 miles, in a little over eight minutes. In one year it travels six million-million miles and such a distance is the astronomer's yard stick, the light-year. We quote the distance of any star by giving the number of years that light requires to come from it to us.

The nearer stars have their distances determined by the ordinary surveyor's method of triangulation, using as our base the distance between the earth and sun. This method enabled the determination of the distances of a few hundred of the nearer stars. The nearest one is about 4¼ light-years distant. Others are at distances of 6, 8, 10 and more light-years. There are only about half a dozen so far discovered at distances less than ten light-years. This surveyor's method breaks down at greater distances than a couple of hundred light-years and then other methods have to be adopted.

It was a very interesting bit of work to play with the results secured for the few hundred stars whose distances were thus found. of the same apparent brightness, of the same colour and at the same measured distance from us. We could not but assume that they were of a similar character, of the same model, if you please. Then others were found of the same apparent brightness in the sky but whose distances differed greatly. If one was twice as far away as another it stood to reason that it must be intrinsically much brighter than the other if it could shine from twice the distance and still appear as bright as the other. By adopting a standard distance and referring all to that distance one could appraise them at their true relative values of brightness. The standard distance chosen was 32.6 light-years, and when all the stars closer than that distance were in imagination put back to that distance and those at greater distances were brought up and lined up with the others, a wonderful discovery was made. If our star, the sun, were assumed to be at the standard distance then there

were some stars hundreds of times as faint as our sun and on the other hand there were others hundreds of times as bright as it.

That discovery was made just a few years before the war, and since then other great discoveries based upon it have been made. We know now that giant stars exist whose real brightness is 10,000 times that of our sun and at the other end of the scale are dwarfs emitting only 1/10,000 of the sun's light. A close examination of the analysed light of the various grades of stars reveals tell-tale markings peculiar to that grade of star alone. Thus by examining the light of a star of unknown distance we can assign it to its proper place in the scale of real brightness. Then a moment's calculation suffices to deduce how far away it must be to appear as bright as it does. This method of getting distances was a great advance on the surveyor's which could carry us out to limited distances only. There is practically no limit to which we can penetrate by this method, provided we can get enough light from the star to pass through our analyzer and show these tell-tale markings. Many observatories have been engaged upon this work since the war, among them our own at Victoria, which determined the distances of 1,100 stars by this method.

We have thus now a great mass of data as to the distances of several thousands of stars, and it is in this way we have learned that in the plane of the Milky Way they extend to much greater distances than in a direction at right angles thereto. Indeed, long exposure photographs in the direction of the Milky Way give one the impression of an infinite number of stars, so closely packed are the star images, like pin-points of light on the plate. Actually these same stars are separated by distances of several light-years, comparable to the distance of our sun from any other star.

A few moments ago I said the space occupied by these millions of stars might be likened to two dinner plates placed face to face. The long diameter of the volume, that is in the direction of the Milky Way, is of the order of 300,000 light-years; the thickness, at right angles, is much less, possibly not more than one-tenth of that amount. In this discoidal shaped space then, dwell the stars of our universe, whose number, according to the latest estimates,

is of the order of thirty billions. Big stars and little stars, hot stars and cooler ones, fast moving ones and slower-going ones make up the assembly; and in the central plane, though off to one side of the centre, shines the one most important to human beings —our own sun.

## XIX. ISLAND UNIVERSES

(May 8, 1929)

Last month I was speaking to you on the extent of our stellar universe, sometimes spoken of as the galactic universe, since it is symmetrical in the heavens about the Galaxy or Milky Way. We learned that, in shape, it was somewhat like a watch, the long diameter being of the order of 300,000 light years, the shorter one about one-tenth of that amount; and that this universe comprised about 30 billions of stars, big and little, scattered throughout its vast extent.

To comprehend such dimensions, of course, taxes one's imagination to the limit. To think that we have knowledge of stars by their light now reaching us, which left them tens of thousands of years ago is, of course, an astounding thing, and suggests the grand scale on which even our own particular universe is designed. But I want to give your imaginations a little more stretching and bring to you a conception of a greater universe still.

To that end, I must recall that two months ago I described certain variable stars called Cepheids, whose variations of light were of such a peculiar and definite character that they could always be recognized wherever found, whether nearby or in the most distant reaches of space. The period of pulsation or throbbing which causes the variation of light, bears a definite relation to the actual luminosity, or sun-power, of the star in question, and by simply determining its period the real brightness, and hence the distance, was easily deduced. Now in the southern hemisphere are two cloudlike aggregations of stars, visible to the naked eye as two patches of light, which are known as the Magellanic Clouds. They were so named, I believe, in honour of the great Portuguese navigator, Magellan. In the smaller of these two Clouds were found

several score of these blinking variables of the type under consideration, though of exceeding apparent faintness. If such extreme faintness was due to their great distance these variables might be considered counterparts of those in our own regions of space. The question was,—Could we rightly assume that in those presumably distant regions of space such variables had similar characteristics to those nearby us? Might they not, after all, be something entirely different? In this case we could not use them as distance indicators.

I can illustrate my point in this way. Suppose you were in a deep valley surrounded by mountains. You wish to know how far away are the mountains. Around you grew ferns a few feet high whilst nearby rose fir trees 150 feet high. Looking through a telescope at the distant mountains you perceived vegetation growing upon their slopes which you at first took, naturally, to be a forest with trees similar to those about you. From the angular dimensions of the trees as viewed in the telescope, coupled with your knowledge of the height of those around you, you could calculate the distance of the mountains. But what an awful mistake if what you had taken for trees should in reality be only ferns; then you would have made the distance fifty times too great. That would be trifling, however, to the mistake in the distance derived for these Magellanic Clouds if what seems to us to be Cepheid variables are really not the true article after all.

Nature, however, appears to be fairly uniform throughout the universe, and there are other reasons which lead us to believe that these are genuine Cepheids, and that wherever stars are found winking and blinking in this characteristic manner they are all built on similar models. Granted then, that those found in the Magellanic Clouds are counterparts of well-known ones nearby us in space, we can use them to deduce the distance of the Cloud. At Harvard College Observatory Shapley utilized the results from a few score of such Cepheids in the Lesser Cloud to show that it was situated at a distance of about one hundred thousand light years from us. If we were to liken our galactic universe to a continent, say North America, then these Clouds could be thought of as large islands in the Atlantic or the Pacific.

But Shapley used this method to give us the distances of other star clusters, namely those known as globular clusters. There are seventy or more of such well-known aggregations of stars, which appear to be more or less compact in form as if globular in shape. The best known one in the northern hemisphere is that in the constellation Hercules and which appears to the naked eye as a rather fuzzy star, decidedly faint. Long exposure photographs reveal many thousands of faint stars, the total number in the cluster being approximately 50,000. A photograph of this beautiful cluster is to be seen in our show-case at the observatory; be sure to see it when you visit the institution. Now among the faint stars in the cluster he found many with this distinct type of variation which I have been speaking of, and from many such periods which he obtained, he was enabled to deduce the distance as 35,000 light years. In the same way he found these tell-tale variables in other globular clusters, and was able to deduce their distances. His results show that these distances range all the way from 21,000 to 200,000 light years. No wonder, then, that aggregations of stars numbering 50,000 or upwards, appear to us as a single fuzzy star when seen from such immense distances.

These globular clusters lie along the plane of the Milky Way and would seem to be coterminous with the limits of our own galactic universe. More are seen in one direction from us than in the opposite direction, and it is assumed our solar system is situated somewhat to one side of the centre. It was from such studies that the long diameter of our galactic universe was set down as roughly 300,000 light years as given earlier in this talk.

But then again long exposure photographs reveal to us the presence in the heavens of cloudlike patches which until recently no telescope would resolve into stars. A few of these are filmy, irregular masses which from other lines of evidence are known to consist of the gases hydrogen, helium, as well as certain constituents of our atmosphere, the latter being in an unusual condition. But there are a great number of objects of compact formation, the analysis of whose light suggested that they consisted of multitudes of individual stars. Most of these objects have a spiral character,

and are known as spiral nebulae. Until the 100-inch telescope at Mount Wilson entered the field none of these had ever been resolved into stars, but this telescope is powerful enough, when seeing conditions are the very best, to resolve into individual stars the spiral nearest to us, the Andromeda Nebula. I have not had the privilege of such a sight, but those astronomers who have had tell me it is a wonderful thing to see the nebulous patch break up into needle-points of light under the powerful resolution of the telescope.

Now romantic as it may appear to be, we find our characteristic Cepheid inhabiting this section of space also. They say "Wherever you go, you'll find a Scotchman"; well, wherever we go in space, apparently, these Cepheid variables are present. It is a very fortunate thing that such is the case, for again they tell by their extreme apparent faintness that the nebula in which they are located is at the inconceivable distance of nearly one million light years. Moreover, nebulae of smaller angular dimensions, and hence likely more distant, abound in the heavens, their number being of the order of several millions.

Here then we have our larger conception of the universe. Our own particular one is the largest of all, having a diameter of 300,000 light years, and comprising 30 billions of suns. Each of these other numerous spirals are similar universes, though on a smaller scale both as regards numbers and dimensions. The closest one to us is the Andromeda spiral and its distance is approximately a million light years. How much farther those of smaller angular dimensions may be we can only infer from such smaller size, until we have larger telescopes to resolve them into individual stars. There is a group of about 100 of these small nebulae in the constellation Virgo whose distance has been estimated to be ten million light years.

In Shapley's happy phrase then, our own universe may be likened to a continent; these others, islands, and the entire universe would include not only the continent, but the islands of the seas as well.

# RADIAL VELOCITY DATA OF EIGHT A-TYPE STARS

By R. M. Petrie.

The accompanying summary of radial velocities is intended to be supplementary to those given in *Publications of the Dominion Astrophysical Observatory*, Volume IV, No. 7. Further plates were secured of some of the stars in that list after the material had been published and in two cases the measures here given are of stars not previously observed by the writer. The plates were made and measured with the apparatus described in the paper just mentioned. It has been found that the final measures are not greatly different from those formerly determined except in the case of H.R. 7086 and H.R. 8970, which now appear to be spectroscopic binaries.

| Star | 1900 R.A. | 1900 Decl. | Mag | Type | Plates | Range | Mean Vel. | p.e. |
|---|---|---|---|---|---|---|---|---|
| | h m | ° ′ | | | | | | |
| H.R. 4555 | 11 48.7 | 0 07 | 6.40 | A5 | 3 | + 3.3 to +14.1 | + 9.3 | 2.1 |
| H.R. 6709 | 17 55.2 | 0 38 | 6.29 | A2 | 7 | −46.7 to + 8.6 | s.b. | |
| H.R. 7085 | 18 44.5 | 0 44 | 6.26 | Ao | 4 | −57.5 to −33.0 | −45.8 | 3.5 |
| H.R. 7086 | 18 44.6 | 19 13 | 5.82 | Ao | 5 | −29.0 to +33.7 | s.b. | |
| H.R. 7313 | 19 12.8 | 1 52 | 6.12 | Ao | 5 | −49.0 to −21.2 | −30.1 | 3.3 |
| H.R. 8174 | 21 17.6 | 80 48 | 6.02 | A2 | 4 | − 3.6 to + 0.1 | − 2.2 | 0.5 |
| H.R. 8605 | 22 31.6 | 11 11 | 6.40 | Ao | 4 | −18.4 to − 8.0 | −11.3 | 1.6 |
| H.R. 8970 | 23 34.9 | 9 07 | 6.07 | A2 | 5 | − 4.8 to + 4.8 | s.b. | |

Ann Arbor, Mich.,
April, 1929

# REVIEW OF PUBLICATIONS

*Bahnbestimmung der Planeten und Kometen*, von Dr. G. Stracke, 365 pages, 6 x 9½ inches. Berlin: Julius Springer, 1929; price, 28.60 RM.

The author has succeeded in producing a book which is a comprehensive treatment of this subject without being too voluminous. There is no treatise in the English language which covers the same ground and the book should be obtained by those interested in orbital computations. Space has been conserved by leaving out much irrelevant material often included, such as chapters on least squares, interpolation, and mechanical quadratures. Space is also saved by making full use of each page, by the conservative size of the diagrams, by using a somewhat smaller print for formulae and numerical examples, and the result is a book containing as much material as is ordinarily spread into five hundred or more pages.

The book is divided into six parts, containing twenty-three chapters in all. The first part treats of the heliocentric and geocentric motion. The second part deals with the observational material for the computation of the elements, together with a discussion of the rejection of observations with large errors, and the effect of small errors. The third part takes up the various methods of computing the orbit. The Gaussian methods are treated very fully, but we could wish that more had been given about the Laplacian methods and particularly Leuschner's method. The fourth part gives methods of computing the ephemeris. The fifth part includes the computation of special perturbations, while in the sixth are found methods of improving orbital elements.

At the end of each part is a collection of formulae, and for the first time so far as known to the writer, they are arranged both for logarithmic and machine computation. This is a good feature. An index to published treatises and papers on orbit determinations will be found at the end of the volume. R.K.Y.

# NEWS AND COMMENTS

The Forty-second Meeting of the American Astronomical Society will be held at the Dominion Observatory, Ottawa, August 27-29, just 18 years after the twelfth meeting held there, August 23-25, 1911. About thirty-five members attended the 1911 meetings, but accompanying friends and others in Ottawa raised the attendance to about eighty. With increased membership in the Society and the fact that delightful motor trips on good highways are now possible, it is expected that many more members with their friends will make the trip to Ottawa this year. Members of the Royal Astronomical Society of Canada will be welcomed at the meetings, and those who are not already members of the American Astronomical Society should consider having their names submitted for membership at the meeting of the Council just before the sessions commence. Hotel reservations should be made early. Motorists who wish to camp will find every convenience at the city tourist camp at Lansdowne Park, about a mile from the hotels and from the Dominion Observatory.

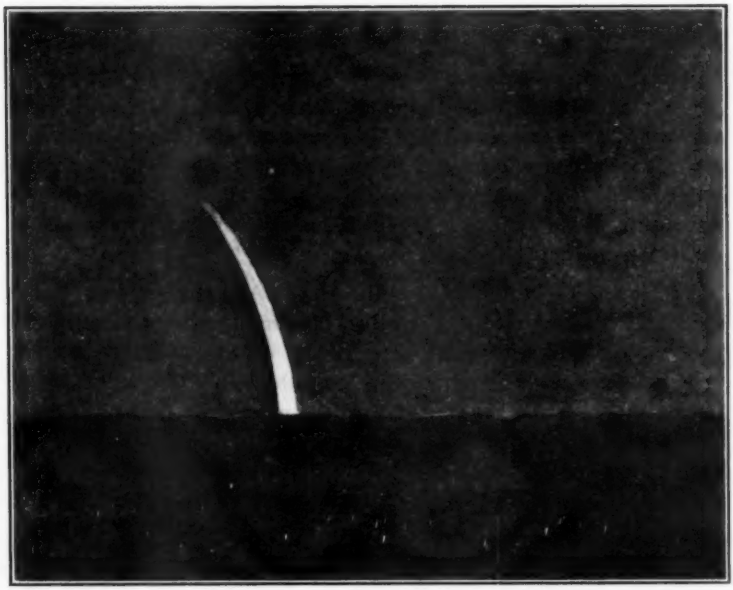
Dr. William Wallace Campbell, since 1901 Director of the Lick Observatory, and since 1923 president of the University of California, has announced his intention of resigning from the presidency of the university at the end of the next academic year. Astronomers will be pleased that this will give him more freedom for his astronomical work.

From *Science* we learn that the Lick Observatory will send an expedition to observe the total eclipse of the sun on April 28, 1930, which will be visible in central California and northwestern Nevada. The duration of totality of only a second or two will greatly restrict the observing program.

According to *Science Service*, good observing conditions permitted Dr. John A. Miller (Swarthmore College) in Sumatra, and

northern horizon; and if the entire arc above the horizon had been visible its highest point would have had an altitude of about 29°.

A sketch which accompanied the report is reproduced herewith.



Rainbow Phenomenon seen from Southesk, Alberta, 1 a.m. to 1.02½ a.m., Sunday, May 26, 1929.

## A Halo Seen in 1794

In the *Journal of Duncan McGillivray, Fort George, 1794,* which has just been published by the Macmillan Co. of Canada, appears the following:—

"27th February, about noon, when the firmament around the sun was beautifully adorned with several circles of the colour of the rainbow, intersecting each other in a curious manner;—parallel to the horizon was a large circle passing through the centre of the sun and containing four luminous bodies resembling it;—two of

these (one on each side of the sun) were intersected by a beautiful circle described round the sun as a centre and extending from the horizon almost to the zenith; and several other circles and semi-circles were curiously disposed of in the several parts of the southern hemisphere. This appearance continued for the space of an hour and afterwards vanished gradually."

Fort George was on the Saskatchewan River, not far from the junction of the two branches, in longitude about 105° and latitude about 53°. On February 27 at noon, the sun would be about 29° above the southern horizon. It is interesting to note that the famous complex halo observed near St. Petersburg, Russia, (see Humphreys' *Physics of the Air*, p. 496, 1st ed.) was seen on July 18, 1794.

Remarks on Magnetism and the Aurora (By G. H. Blanchet, D.L.S., dated May 10, 1928).

My station at Tavane (on the west shore of Hudson Bay) is practically on the line of no variation. My transit was set up in an igloo quite free from any disturbance.

The periodic readings which I have taken were generally so consistent that I did not consider it necessary to make more elaborate observations. An exact reading is difficult on account of the small horizontal force; the reading noted was the mean of a number of settings with a range of ten to twenty minutes.

An intermittent magnetic disturbance was caught at the latter part of February. It started without an auroral display, but towards the end for two successive nights we had the most brilliant displays I have ever seen. The last night of the disturbance there was no aurora. Since February there has been very little aurora, and now in the long days it would not be seen.

The outstanding feature of the aurora here throughout the winter has been its characteristic form of a fairly narrow band across the sky from the southeast to the northwest, passing south of zenith. It is usually brighter in the southeast. It has been rare to see it in the north or even north of the zenith.

The display of February 26 took the form of streamers radiating

from the zenith to the horizon and extending from the east through the south to the west. They had a rapid motion as of a ribbon shaking in the wind, and the brightness sometimes in strong colours ran up and down. It lasted from 8 to 8.40, then almost faded and later appeared in its usual form.

On the 27th it again appeared about 8 with great brilliancy as a waving line of pencilled lights extending almost to the zenith and again from the east through the south to the west, most striking in the east. It became dim after 9 and faded to a fringe at the eastern horizon about 10.

On the next night and afterwards the aurora took its conventional form and was dim.—*Forwarded by F. V. Seibert, Department of the Interior.*

### Amateur Telescope Makers

In the *Scientific American* each month is a department entitled "The Amateur Astronomer", which is conducted by Mr. Albert G. Ingalls, associate editor, and which deserves high commendation for the efficient assistance it is giving to amateurs who are trying to construct their own telescopes and then to use them in studying the heavens.

For many years, following the distinguished example of Sir Isaac Newton and Sir William Herschel, the making of telescope mirrors has been the admirable hobby of a select few. About 1920 Mr. Russell W. Porter, after several trips to the Arctic regions, returned to Springfield, his home town in Vermont, and became associated with a well-known firm of manufacturers of machine tools. With the cordial approval of the head of the company he encouraged the workers to make telescopes, and the response was remarkable. Then Mr. Ingalls became interested in the movement. The result was a series of articles in the *Scientific American* and a little book on "Amateur Telescope Making", of which a revised and enlarged edition appeared last year.

In each issue of the magazine there are pictures of instruments which have been produced, together with a recital of experiences by the makers. As an example I quote from the June issue an

account of the work of Thomas Rhodes, of Fort Dodge, Iowa, a high school student. Two years ago, after reading the book, he made a 6-inch mirror and then he undertook a 12-inch one which he now has mounted equatorially. The closing paragraph of his letter is as follows:— "I have doubly profited by my experiences as an amateur telescope maker. The construction of the mirror itself was so intensely interesting that I would feel repaid if there was no result other than the production of a perfect paraboloidal curve. But I have been admitted into the wonders of the heavens. Before I constructed my first telescope I neither knew nor cared anything for astronomy. I now spend many evenings in exploring the sky, and although I do not know much about the movements of the celestial bodies as yet, I am diligently studying the science and hope to learn more."

C.A.C.

# MEETINGS OF THE SOCIETY

## AT MONTREAL

March 20—The seventh meeting for the present season was held in the Macdonald Physics Laboratory, at 8.15 p.m. The President occupied the Chair.

One new member was elected, Rev. E. E. Dawson, Lacolle, P.Q.

The lecturer was Professor A. H. S. Gillson, who chose as his subject, Tides.

The Mediterranean peoples knew little of the tides and an interesting account was read of the consternation of Alexander the Great and his expedition on reaching tide water at the mouth of the Indus.

The phenomena of tides and tidal currents were described by means of diagrams illustrating lunar day, spring tide, neap tide, the reason for high tide preceding the moon until 1st quarter and lagging behind during the next quarter phase, the relative pull of moon and of sun (7:3) and the disturbing influence of irregular oceans and land barriers.

After outlining some of the Newtonian calculations, Lord Kelvin's researches on the rigidity of the earth were described. The observed tides are about 2/3 of what they should be if the earth were perfectly rigid, hence there must be earth tides of the order of 9 inches. This was tested experimentally by Michelson and Gale in 1913, who confirmed the earth's elasticity as equal to that of steel. There being no lag in the earth tide, there is no viscosity.

The effects of Tidal Friction were discussed—the slowing up of the earth's rate of rotation by 1/1000 sec. per century and the reaction on the moon, causing it to recede. This represents 2,100 million horse power. The large oceans only provide 0.1% of this power, but small constricted regions like the Irish Sea, 2%; English Channel, 4%; North Sea, 2%; Hudson Strait, 0.6%; the Behring Sea, etc., account for almost the entire effect.

The ultimate effect of this frictional retardation will be to make the day equal to the month equal to 47 of our present days, in about fifty thousand million years, after which the *day* will exceed the *month* as is now the case with Mars' inner moon. Solar tides will then exert an influence tending to cause the moon to spiral in towards the earth. On the close approach of our satellite, perhaps we may anticipate its tidal disruption to form a girdle about the earth like Saturn's rings.

Looking into the Past, the Resonance Theory of the birth of the moon was outlined, taking place some three thousand million years ago when the earth's *day* was about 4 hours long, bringing about resonance between the tidal forces and the natural pulsations of the earth.

In conclusion the Tidal Theory of the formation of the Solar System was outlined.

Mr. James Wright moved a hearty vote of thanks and after some discussion and questions the meeting adjourned.

A. Vibert Douglas, *Secretary*.

# The Royal Astronomical Society of Canada

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## THE ROYAL ASTRONOMICAL SOCIETY OF CANADA

The objects of the Society, incorporated in 1890, are:

(*a*) "To study Astronomy, Astrophysics and such cognate subjects as shall be approved of by the Society and as shall, in its opinion, tend to the better consideration and elucidation of Astronomical and Astrophysical problems; and to diffuse theoretical and practical knowledge with respect to such subjects.

(*b*) To publish from time to time the results of the work of the Society; and,

(*c*) To acquire and maintain a Library, and such apparatus and real and personal property as may be necessary and convenient for the carrying into effect of the objects of the Society."

For many years the Toronto organization existed alone, but now the Society is national in extent, having active Centres in Montreal, P.Q.; Ottawa, Ont.; Toronto, Ont.; London, Ont.; Winnipeg, Man.; and Victoria, B.C. Among its 800 members are a number of the leading astronomers and scientists of the world, many amateurs, and in addition, many laymen who are interested in the culture of the science.

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